Model Analysis of Response of Bermudagrass to Applied Nitrogen

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ABSTRACT

The extended logistic model of crop response to applied nutrients provides quantitative coupling of seasonal dry matter (Y), plant N uptake (N_u), and plant N concentration (N_c) with applied nutrient (N). It predicts a hyperbolic relationship between Y and N_c with N_u. Analysis of data from numerous studies has confirmed the model. In this article the model was applied to data for Midland and Tifton 44 bermudagrass (Cynodon dactylon L.) grown on the same soil in Oklahoma. Results showed that the intercept parameters b and b_n, as well as the nitrogen response coefficient c, were common to the two cultivars. The difference was accounted for in yield parameter A and plant N uptake parameter A_n. Applied N required to achieve 50% of maximum yield was 92 kg ha⁻¹ for both cultivars.

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INTRODUCTION

Overman et al.\textsuperscript{[1]} have published an extended logistic model of forage grass response to applied N. The model includes functions for dry matter and plant N accumulation over the growing season. Data from the literature\textsuperscript{[2]} for dallisgrass (\textit{Paspalum dilatatum} Poir) were used to illustrate characteristics of the model. The model has been applied to the annual corn (\textit{Zea mays} L.) as well.\textsuperscript{[3]} In this analysis the model is used to evaluate model parameters for two cultivars of bermudagrass grown in Oklahoma.

MODEL DESCRIPTION

In the extended logistic model seasonal dry matter yield ($Y$), plant N uptake ($N_u$), and plant N concentration ($N_c$) are related to applied nitrogen ($N$) by the equations

$$Y = \frac{A}{1 + \exp(b - cN)} \quad (1)$$

$$N_u = \frac{A_u}{1 + \exp(b_u - cN)} \quad (2)$$

$$N_c = \frac{N_{cm} \left[ 1 + \exp(b - cN) \right]}{1 + \exp(b_n - cN)} \quad (3)$$

where $A =$ maximum yield at high $N$, Mg ha\textsuperscript{-1}; $A_u =$ maximum plant N uptake at high $N$, kg ha\textsuperscript{-1}; $N_{cm} = A_n/A =$ maximum plant N concentration at high $N$, g kg\textsuperscript{-1}; $b =$ intercept parameter for yield; $b_u =$ intercept parameter for plant N uptake; $c =$ response coefficient for applied N, ha kg\textsuperscript{-1}. The phase relation follows from Eqs. (1) and (2) and is given by

$$Y = \frac{Y_m N_u}{K_n + N_u} \quad (4)$$

where the phase parameters are related to logistic parameters by

$$Y_m = \frac{A}{1 - \exp(-\Delta b)} \quad (5)$$

$$K_n = \frac{A_u}{\exp(\Delta b) - 1} \quad (6)$$
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with

$$\Delta b = b_n - b$$

(7)

Now Eq. (4) can be rearranged to the linear relationship between plant N concentration ($N_c$) and plant N uptake ($N_u$)

$$N_c = \frac{N_u}{Y} = \frac{K_n}{Y_m} + \frac{1}{Y_m}N_u$$

(8)

DATA ANALYSIS

Data for this analysis are taken from a field study at Stillwater, OK with Midland and Tifton 44 bermudagrass.\[4\] The soil was Kirkland silt loam (fine, mixed, superactive, thermic Udertic Paleustolls). Average harvest interval was 4.7 wk, with treatments replicated four times. Seasonal data are listed in Table 1. Response data are shown in Fig. 1 with phase plots in Fig. 2. Evaluation of model parameters is as follows. It is apparent from the phase plot that $N_c$ vs. $N_u$ follows a linear relationship. By linear regression we obtain

Midland bermudagrass:

$$N_c = \frac{K_n}{Y_m} + \frac{1}{Y_m} = 12.7 + 0.0282N_u \quad r = 0.9998$$

(9)

$$Y_m = 35.4 \text{ Mg ha}^{-1}, \; K_n = 450 \text{ kg ha}^{-1}$$

(10)

$$Y = \frac{Y_mN_u}{K_n + N_u} = \frac{35.4N_u}{450 + N_u}$$

(11)

Tifton 44 bermudagrass:

$$N_c = 13.4 + 0.0344N_u \quad r = 0.9900$$

(12)

$$Y_m = 29.1 \text{ Mg ha}^{-1}, \; K_n = 390 \text{ kg ha}^{-1}$$

(13)

$$Y = \frac{29.1N_u}{390 + N_u}$$

(14)

with very high correlation coefficients ($r \geq 0.99$). Analysis of plant N uptake data in Table 2 leads to the logistic parameters $A_n = 275 \text{ kg ha}^{-1}, \; b_n = 1.60,$
and $c = 0.0120 \text{ha kg}^{-1}$. By trial and error we then estimate $A_n(\text{Midland}) = 290 \text{Mg ha}^{-1}$ and $A_n(\text{Tifton 44}) = 260 \text{Mg ha}^{-1}$. These values can be combined with the phase parameters to obtain

$$
\Delta b = \ln \left( 1 + \frac{A_n}{K_n} \right) = \ln \left( 1 + \frac{290}{450} \right) = \ln \left( 1 + \frac{260}{390} \right) = 0.50
$$

which leads to a value for parameter $b$ of

$$
b = b_n - \Delta b = 1.60 - 0.50 = 1.10
$$

From values of $Y_m$ and $\Delta b$ parameter $A$ is calculated from

**Midland bermudagrass** : 

$$
A = Y_m [1 - \exp(-\Delta b)]
$$

$$
= 35.4 [1 - \exp(-0.50)]
$$

$$
= 14.0 \text{Mg ha}^{-1}
$$

**Tifton 44 bermudagrass** : 

$$
A = 29.1 [1 - \exp(-0.50)]
$$

$$
= 11.5 \text{Mg ha}^{-1}
$$

A summary of model parameters is given in Table 3.

Response curves in Fig. 1 are drawn from Eqs. (1) through (3) with parameters from Table 3. The phase lines in Fig. 2 are drawn from Eqs. (9) and (12), while the curves are drawn from Eqs. (11) and (14) for Midland and Tifton 44, respectively.

### Table 1. Response of seasonal dry matter yield ($Y$), plant N uptake ($N_u$), and plant N concentration ($N_c$) to applied nitrogen ($N$) for Midland and Tifton 44 bermudagrass grown at Stillwater, OK (1993).a

<table>
<thead>
<tr>
<th>Grass</th>
<th>$N$ (kg ha$^{-1}$)</th>
<th>$Y$ (Mg ha$^{-1}$)</th>
<th>$N_u$ (kg ha$^{-1}$)</th>
<th>$N_c$ (g kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midland</td>
<td>45</td>
<td>4.38</td>
<td>63.5</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>6.97</td>
<td>110.6</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>10.33</td>
<td>184.8</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>13.43</td>
<td>274.9</td>
<td>20.5</td>
</tr>
<tr>
<td>Tifton 44 bermuda</td>
<td>45</td>
<td>5.36</td>
<td>88.2</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>6.29</td>
<td>104.4</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>7.82</td>
<td>147.5</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>11.29</td>
<td>245.2</td>
<td>21.7</td>
</tr>
</tbody>
</table>

a Data adapted from Taliaferro et al.[4]
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Figure 1. Response of seasonal dry matter (Y), plant N uptake (N_u), and plant N concentration (N_c) to applied nitrogen (N) for Midland and Tifton 44 bermudagrass grown at Stillwater, OK. Data adapted from Taliaferro et al. Curves drawn from Eqs (1) through (3) with model parameters from Table 3.
DISCUSSION

The extended logistic model predicts the phase relations for these data very well (Fig. 2). The model provides reasonable description of the response curves as well (Fig. 1). We conclude that parameters $b$, $b_n$, and $c$ are common for the two cultivars. Parameters $A$ and $A_n$ account for the difference between the two. Note that as $N$ increases to high values, $Y \to 14.0$ and $11.5 \text{ Mg ha}^{-1}$, $N_u \to 290$ and $260 \text{ kg ha}^{-1}$, and $N_c \to 20.7$ and $22.6 \text{ g kg}^{-1}$ for Midland and Tifton 44, respectively. For reduced $N$ (depletion of soil $N$, $N < 0$), the model predicts that $Y \to 0$ and $N_u \to 0$. It can be shown that the lower limit of plant $N$...
concentration, \( N_{cl} \), is given by

\[
N_{cl} = N_{cm} \exp(-\Delta b) = N_{cm} \exp(-0.50) = 0.607N_{cm}
\]  (19)

so that \( N_{c} \) approaches a lower limit of \( N_{cl} = 12.6 \) and 13.7 g kg\(^{-1}\) for Midland and Tifton 44, respectively. It follows that plant N concentration is bracketed by \( N_{cl} \leq N_{c} \leq N_{cm} \).

It is easily shown that applied N, \( N_{1/2} \), to reach 50% of maximum yield, \( Y/A = 0.5 \), is given by

\[
N = N_{1/2} = \frac{b}{c} = \frac{1.10}{0.0120} = 92 \text{ kg ha}^{-1}
\]  (20)

for both cultivars. This also happens to be the point of maximum incremental

**Table 2.** Evaluation of logistic model parameters for Midland and Tifton 44 bermudagrass grown at Stillwater, OK (1993).

<table>
<thead>
<tr>
<th>( N_u ) (kg ha(^{-1}))</th>
<th>N (kg ha(^{-1}))</th>
<th>Midland</th>
<th>Tifton 44</th>
<th>Avg</th>
<th>( A_u/N_u - 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>63.5</td>
<td>88.2</td>
<td>75.8</td>
<td>2.63</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>110.6</td>
<td>104.4</td>
<td>107.5</td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>184.8</td>
<td>147.5</td>
<td>166.2</td>
<td>0.655</td>
<td></td>
</tr>
<tr>
<td>360</td>
<td>274.9</td>
<td>245.2</td>
<td>260.0</td>
<td>0.0577</td>
<td></td>
</tr>
<tr>
<td>( A_u )</td>
<td>275</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( b_u )</td>
<td>1.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( c )</td>
<td>0.0120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r )</td>
<td>-0.9975</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.** Summary of logistic model parameters for Midland and Tifton 44 bermudagrass grown at Stillwater, OK.

<table>
<thead>
<tr>
<th>Grass</th>
<th>( A ) (Mg ha(^{-1}))</th>
<th>( A_u ) (kg ha(^{-1}))</th>
<th>( N_{cm} ) (g kg(^{-1}))</th>
<th>( b )</th>
<th>( b_u )</th>
<th>( c ) (ha kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midland bermuda</td>
<td>14.0</td>
<td>290</td>
<td>20.7</td>
<td>1.10</td>
<td>1.60</td>
<td>0.0120</td>
</tr>
<tr>
<td>Tifton 44 bermuda</td>
<td>11.5</td>
<td>260</td>
<td>22.6</td>
<td>1.10</td>
<td>1.60</td>
<td>0.0120</td>
</tr>
</tbody>
</table>
increase in biomass with applied N, which can be calculated from
\[
\left( \frac{dY}{dN} \right)_{\text{max}} = \frac{Ac}{4} 
\]
and which leads to 0.042 and 0.035 Mg kg\(^{-1}\) for Midland and Tifton 44, respectively. These values indicate that Midland is slightly more efficient in utilization of applied N than Tifton 44.

It should also be noted that the experimental design provided an excellent range in the data for model parameter evaluation. The highest values of \(Y\) and \(N_u\) were above 94\% of estimated maximum in both cases.

REFERENCES